Using Data Manager® 2000 to remotely diagnose gas compressor rotating stall

by Sebastiaan Teeling
Machinery Vibration Specialist, Machinery Management Services
Bently Nevada Corporation
sebastiaan.teeling@bently.com

The offshore platform in this article is a staffed gas production facility located on the Dutch continental shelf of the North Sea. Gas from unstaffed production platforms is conveyed via pipelines to the staffed platform, where it is processed, compressed, and dried. The gas is then exported, through pipelines to a terminal in The Netherlands.

The machine train

Recently, two new gas compressor units were installed on the platform in order to continue gas production as the field pressure decreased. Each unit consists of a 14 MW aeroderivative gas turbine, a power turbine, a speed increasing gearbox, and a back-to-back type barrel compressor (Figure 1). The units were designed to run separately or in parallel with each other.

Online machinery management system

Since safety is a primary issue on offshore platforms, and because the two compressors are essential for gas production, the platform operator decided to equip the units with a Bently Nevada 3300 Series Machinery Protection System. This was combined with Bently Nevada's Data Manager® 2000 (DM2000), a computerized machinery management system which continuously collects and stores data from all machinery protection system inputs during steady state operation. Data is also sampled during important operating conditions, such as transient operation (startup and shutdown) and protection system alarms. This data is used to evaluate the machine's condition and to optimize the operation of the compressors.

Remote diagnostic capabilities

The operator uses Bently Nevada's Machinery Management Services (MMS) to assist in diagnosing machinery data. Since DM2000 offers access to both real-time and archived data files via a modem connection, remote diagnostics is possible from any Bently Nevada office. As this case history will illustrate, the ability to rapidly resolve machinery problems is greatly enhanced by this capability.

Occurrences

In September 1997, a few months after the units were put into service, Unit B's centrifugal compressor experienced high vibration amplitudes during the startup of the machine train. At 80 µm pp, the unit tripped. Because the unit was needed for production, the operator immediately asked Bently Nevada's MMS to log in remotely and analyze the machine problem. When the vibration alarm occurred, the DM2000 system had automatically stored data, which was used to evaluate the condition.

The Bode and trend plots of the

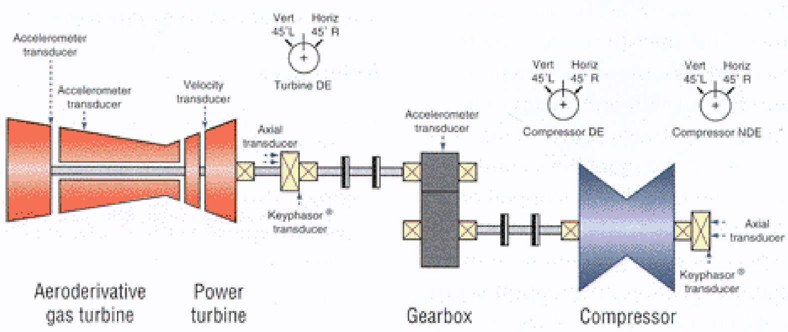

Figure 1. Turbine compressor train diagram.

vibration recorded during the startup, moments before the trip (Figures 2 and 3), show that, during the load increase on compressor B, vibration levels had increased significantly, along with a phase change of approximately 90°.

More important, however, was the shape of the orbit, as can be seen in Figures 4 and 5.

A closer inspection of the vibration data taken during the runup showed that, as the 1X vibration amplitude increased, the shape of the orbit changed into an abnormal, almost square, form. The orbit plot represents the movement of the shaft centerline (if the shaft relative proximity transducer is not moving). One explanation for these square orbits is that the vibration probes were moving as well. MMS, therefore, advised the operator to inspect the casing foundation bolts. These bolts were loose! The manufacturer was called to inspect the unit, as it was still under warranty.

Restart

After the OEM had properly realigned the compressor and correctly tightened the foundation bolts, the unit was ready for a restart. This time, Bently Nevada MMS Engineers were online via modem during the startup. The unit ran up to nearly 7000 rpm without any problems. At 7200 rpm, though, the unit suddenly experienced high vibration amplitude again. Within 2½ minutes, as the speed continued to increase, the vibration amplitude increased from 10 to 110 mm pp, and the unit tripped. At first, operations suspected that the compressor's problem hadn't been solved.

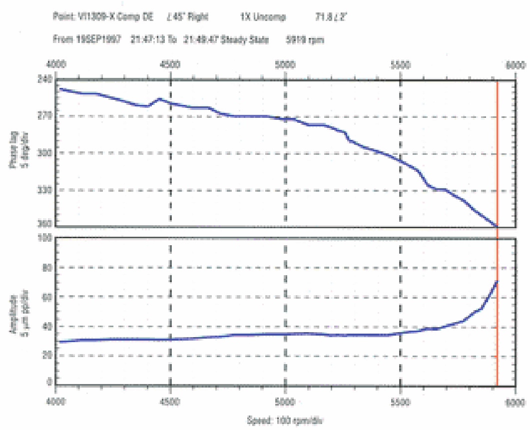

Figure 2. Bode plot of 1X amplitude and phase during startup.

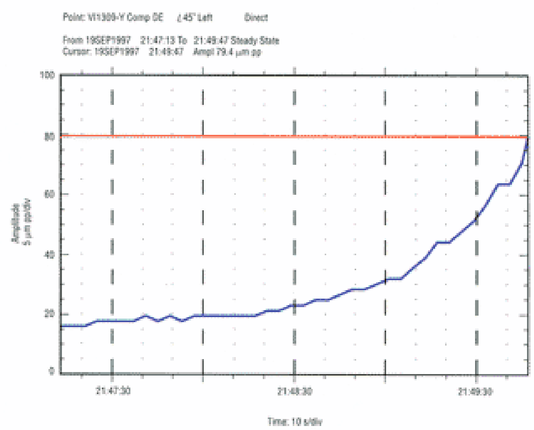

Figure 3. Trend plot of direct vibration amplitude during startup.

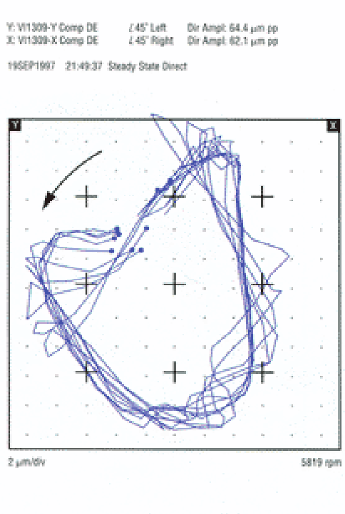

Figure 4. Changing shaft orbit pattern at compressor drive end.

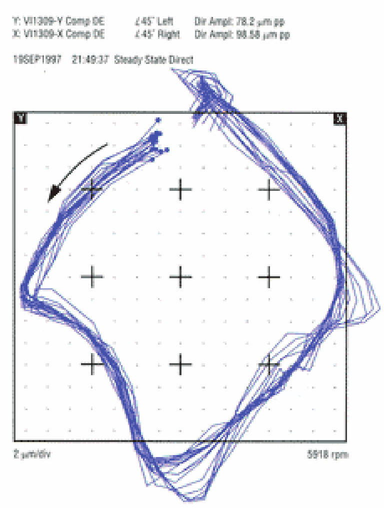

Figure 5. "Square" shaft orbit at compressor drive end just before the trip.

However, machinery data from the DM2000 system showed that the orbit shape and Keyphasor® dot pattern (Figure 6) differed substantially from the earlier orbit, and the machine clearly had a different problem.

MMS was able to identify, in less than 2½ hours, this new malfunction as rotating stall, without setting foot on the platform.

Rotating stall

The vibration data up to 7000 rpm showed a normal 1X amplitude and phase behavior. After that, the machine's vibration response became unstable, and a subsynchronous vibration component dominated the orbit.

The vibration full spectrum cascade plot (Figure 7) shows that this subsynchronous component is forward and at approximately 0.65X running speed.

The most logical explanation for subsynchronous vibration at 0.6X-0.8X rotative speed on centrifugal compressors is rotating stall. Rotating stall is an instability of the coupled aerodynamic/mechanical system resulting in forward whirling of a rotor at a subsynchronous frequency, which tracks the rotative speed. It is caused by boundary layer separation in the compressor which results in partial flow reversal in the diffusers or impellers and circumferentially propagating pressure waves.

Rotating stall can be recognized by subsynchronous vibrations, typically at 0.10X-0.20X rotative speed, when the action occurs in the diffuser, and at 0.60X-0.80X rotative speed, when the action occurs in the impeller.

Editor's note: *In one year's time, rotating stall has been moved from the arena of "witchcraft" to become more widely known due to the contributions of Bently Rotor Dynamics Research Corporation and people like D. Fred Marshall of the Dresser-Rand Company [1].*

Rotating stall generally occurs when a compressor is close to the surge point. The process data, therefore, was checked to see if the compressor had been close to surge. However, neither the process data nor the antisurge control system data showed any indications that the unit had been near surge. As a matter of fact, the compressor bypass valve had been fully open

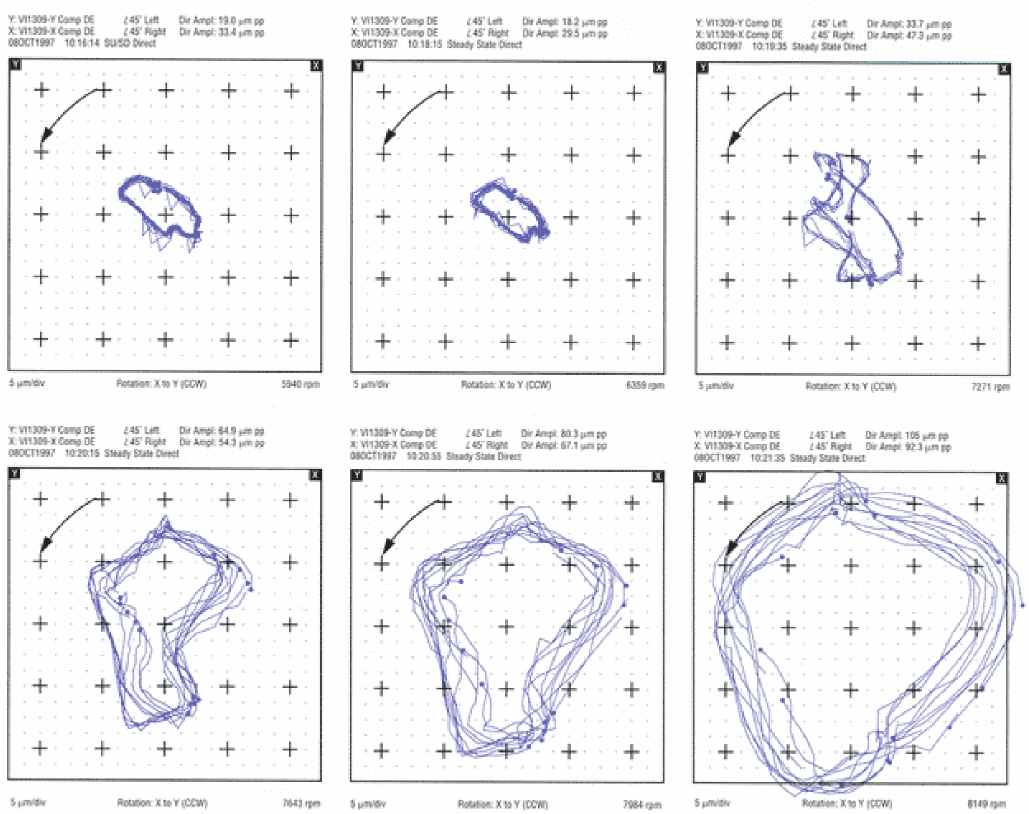

Figure 6. The orbit patterns during the startup of the compressor. At 7271 rpm the orbit shape is dominated by a subsynchronous vibration component, caused by circumferentially propagating pressure waves in the impeller.

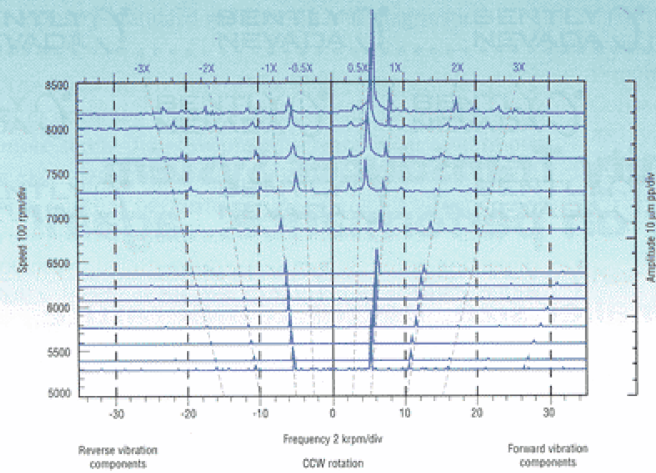

Figure 7. The full spectrum cascade plot clearly indicates that the subsynchronous vibration is tracking running speed at 0.65X and is forward in precession.

during the startup. It appeared that the vibration data and the process data contradicted each other, so the maintenance supervisor organized an inspection of the suction pipe. This inspection revealed some surprising evidence.

Inspection

After opening the compressor inlet strainers, it was seen that large parts of these filters were ripped off and missing. It was concluded that these parts had been sucked into the compressor, so a borescope investigation was performed. As soon as the camera entered the compressor inlet, a large piece of the filter was visible, folded around an inlet guide vane (Figure 8). This piece of filter, which clearly blocked a large part of the compressor inlet, was the reason for the rotating stall at the impeller. Although the compressor inlet and outlet pressure and flow conditions indicated that the unit was far from a surge condition, the filter part affected the inlet flow to such an extent that the operating point in the impeller moved close to the surge limit, and boundary layer separation took place. This caused the characteristic high amplitude, subsynchronous vibration.

Root cause analysis

Further inspections revealed that all the inlet filters of Units A and B had also partially or completely disintegrated. To prevent further damage, the operator decided to remove these filters.

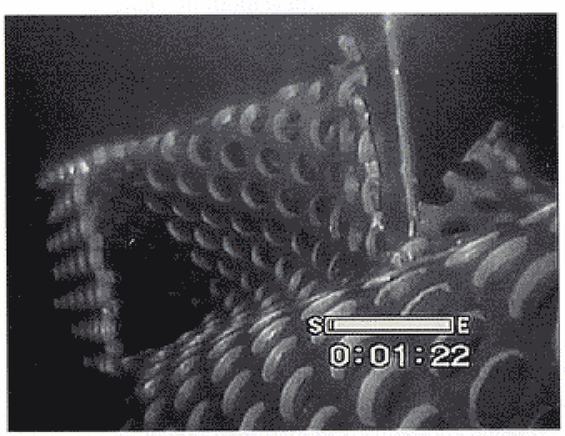

Figure 8. A borescope picture of the compressor inlet eye shows a large piece of the inlet strainer folded around the inlet guide vanes and blocking the compressor inlet eye.

Remote access

Remote access was the critically important capability of the machinery management system that allowed the operator to avert catastrophic machine failure and significant loss of production. The operator had timely recommendations they could act on because the MMS Engineers had access to the online and archived machine data by modem. They produced a timely diagnosis by moving data, not people.

Summary

- Cracks developed on all the filters.
- Excessive vibration on Unit B in September 1997 caused one of the filters to break and get stuck in the impeller inlet eye.
- During the October 1997 startup, rotating stall occurred in the impeller, caused by the partially blocked impeller eye. Since the compressor inlet and outlet overall flow and pressure conditions were normal, no surge was detected by the antisurge system.
- Diagnosis of the malfunction prevented the restart of the compressor and led to the discovery of the broken filters.
- Soon after this event, the operator and Bently Nevada signed a Remote Services contract. Remote diagnostic surveys are now performed at a fixed frequency. The goal of these audits is to prevent or minimize machine problems by early detection.

Contact your local Bently Nevada office for more information.

References:

1. Sorokes, J.M., Marshall, D.F., "A review of aerodynamically induced forces acting on centrifugal compressors, and resulting vibration characteristics of rotors," Proceedings of the 27th Turbomachinery Symposium, Texas A&M, September 1998.
2. Van den Braembussche, R.A., "Stability and range in centrifugal compressors," preprint TMP 1996-12, Von Karman Institute for Fluid Dynamics, Belgium.